Development of Trawl Design by Observation Of Scale Models In A Flume Tank

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CONTENTS

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1. INTRODUCTION

1.1 Full-Scale Trials

The most desirable and conclusive method for evaluating trawl behavior and performance is full-scale, instrumented, comparative fishing trials. Comparative trials should be conducted simultaneously in a well-structured, statistical manner by two similar fishing vessels in close proximity and with similar trawl systems, associated equipment, and towing power. The comparative approach facilitated by the instrumentation of two trawl systems, ref. (6) and (7), allows the effects of alterations in component dimensions of the full gear system to be revealed by a comparison of trawl measurements and resultant catch data. Hence, incremental benefits may be attained by a continuous "tuning" and observation program.

Comparative testing should be conducted on a long-term and repetitive basis with interchange of fishing gear, ancillary equipment, and personnel between vessels. Only in this manner will minor environmental differences be cancelled out and the element of chance removed.

The National Marine Fisheries Service of the U.S.A. and the Fisheries Department of the U.S.S.R. have, in recent years, conducted comparative gear trials with their respective fisheries research vessels "Delaware IV" and "Blesk" in order to determine the optimum design for a standard combination sampling trawl acceptable to both nations for the assessment of certain fish stocks in the N.W. Atlantic.

The standard trawl eventually to be selected is to provide a good sample of fish swimming on or near the bottom, to make possible an estimate of probable fish stocks within the region of concern. Hence, a more efficient system of fishing control and conservation may be instituted on an international level with more credibility than has previously been demonstrated.

One of the trawls selected for testing by the N.M.F.S. is the University of Rhode Island series combination trawl, ref. (3). This trawl was the subject for the scale modeling trials conducted in the flume tank of the Department of Civil & Coastal Engineering of the University of Florida.

1.2 Advantages of Modeling

Comparative fishing trials are not readily available to most fishing gear specialists. The obvious advantages of this method of fishing gear development may be difficult to justify economically when viewed in the light of the immediate high cost of the trials.

Some fishing gear researchers, ref. (1), (2) and (5), believe that experiments conducted on scale models of trawls under controlled conditions may provide the medium necessary to integrate the analytical approach to gear analysis of

the engineer with the comparative approach of the commercial fisherman practiced in the day-to-day working of his trawl.

Commercial trawler skippers tune their gear to achieve optimum performance in a seemingly routine and apparently unconscious manner. The skipper relies upon his previous experience with the effects of gear-component adjustments, obtained on a "try it and see what happens" basis, to insure that his resultant catch rate is competitive with similar vessels fishing in the vicinity. To a commercial fisherman, time is money. The loss of fishing time incurred when undertaking fishing trials of the exhaustive and thorough nature necessary for sound statistical analysis will generally be regarded as an unacceptable luxury. Experience indicates that, while a commercial fisherman is entirely willing to devote his vessel's time to the examination of new or modified gear on a short-term basis, he will be understandably impatient for tangible results and reluctant to devote his time for any extended period without remuneration equivalent to expected fishing return.

Conversely, simulation of the trawl system--together with its fishing environment--utilizing scale models under controlled conditions in a testing tank, allows extended observation of gear behavior and general design characteristics under a great variety of conditions in far less time. The value of this simulation technique for observing trawl behavior will depend to a great extent upon the authenticity of the scale model of the trawl system and the degree of accuracy to which its fishing environment may be duplicated. Building a truly representative simulation is an extremely difficult, if not impossible, task which requires minute attention to modeling laws.

2. SCALE MODELING

2.1 Modeling Laws

In order to obtain a balanced-model representation of a full-scale trawl, a suitable basic scale factor must first be determined. For example, the URI series combination trawl, ref. (3), was examined in scale-model form in order to gain further insight into the structural composition and general design of the trawl net. The largest tank available for testing the models at the time was the hydraulic flume at the University of Florida.

A gratifying by-product of the net modeling trials undertaken at this facility is the bond of mutual cooperation developed between the Department of Civil and Coastal Engineering of the University of Florida and the Department of Fisheries and Marine Technology of the University of Rhode Island. The former department specializes in the theoretical basis for modeling, while the latter concentrates its efforts more toward the practical application of modeling results to net design. These two areas of interest are necessarily complementary for truly effective modeling experiments.

The major dimensions and capacities of the flume tank, which is one of the largest in the world, are as follows:

Length	140 feet
Width of Main Flume	8 feet
Width of Return Flume	4 feet
Maximum Depth	3 feet
Water Velocity	1 to 5 fps (approx. 0.6-3.5 knots)

Although it is possible to use the flume as a towing tank, it was found to be more convenient, from a recording and measurement viewpoint, to use stationary models and to allow the water to flow through and around them rather than to tow the models through still water.

The particular scale factor selected for reducing the URI combination trawl to a size capable of being tested in the flume was 12. Hence, the resultant depth of net from mouth to codend was about six feet with a headline length and footrope length of about five feet and six feet respectively. The model net was set up in the flume as illustrated in Plate 1. A report concerning the trials data and findings is contained in the Section 2.2.

The scale factor used here is defined as the quantity in the full-scale trawl divided by the corresponding quantity in the model. In general terms, reductions to dimensions of a linear nature are made throughout the model by the amount of the basic scale factor. Factors concerning drag resistance and lift, which are dependent on surface area for their value, decrease by the square of the basic scale. Weight and buoyancy forces that rely on volume for their value are reduced by the cube of the basic scale.

The tank experiments were conducted in the manner suggested by Christensen and documented in ref. (1). The fundamental modeling laws may be summarized as follows where subscripts "f" and "m" refer to full-scale and model, respectively.

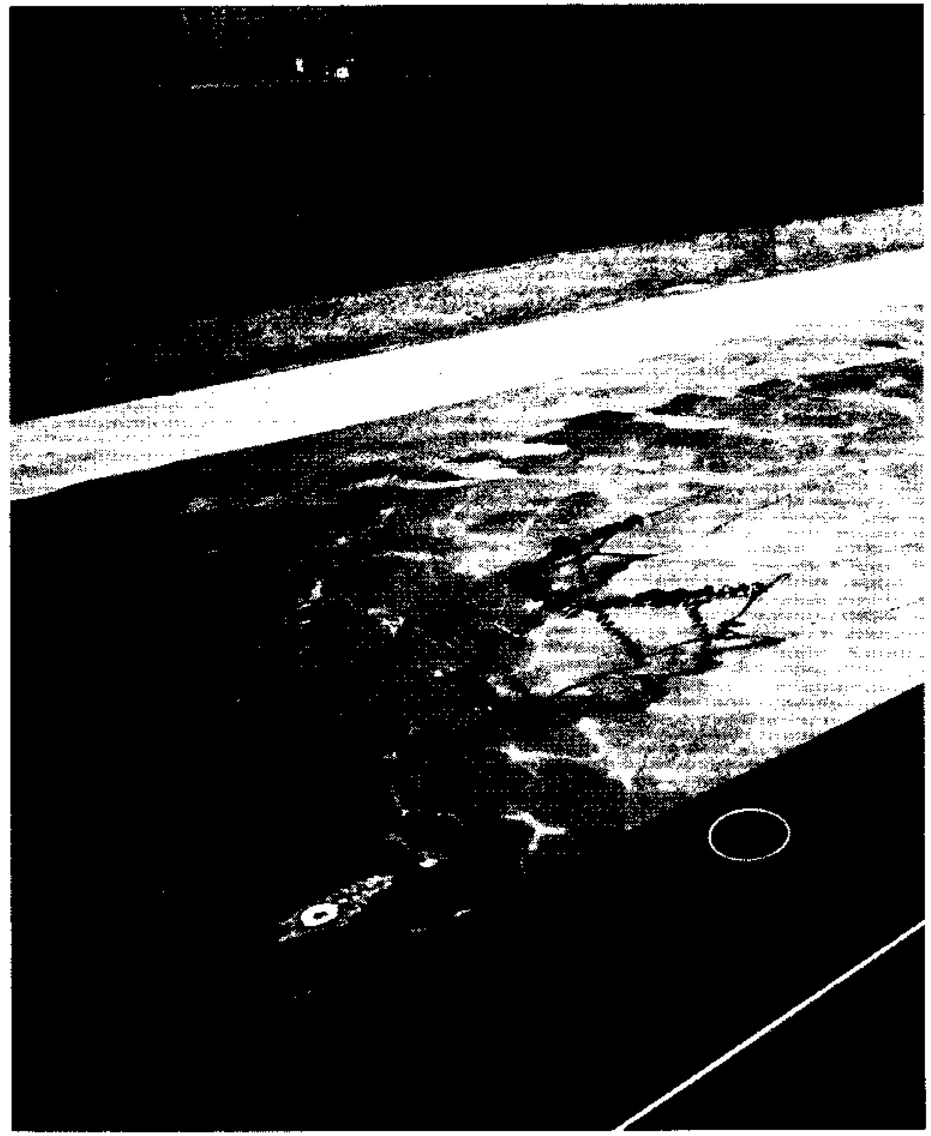


Plate 1. Trawl Model Streamed in the Flume

Length scale: $\lambda = L_f/L_m$ (1)

Time scale: $\tau = T_f/T_m$ (2)

Force scale: $K = F_f/F_m$ (3)

where L, T and F stand for a certain length time and force respectively.

2. Predominant forces on a trawl or its model are inertia, gravity and viscosity of the water, ref. (2) and (4). If the model is not too small, viscous forces have a relatively minor influence, and inertial and gravitational forces can be equated to yield the time scale in terms of the basic length scale.

Thus Time Scale: $\tau = \sqrt{\lambda}$ (4)

and
Velocity Scale: $\frac{\lambda}{\tau} = \sqrt{\lambda}$ (5)

Christensen's treatment, ref. (1), which yields the commonly accepted Froude's model law, equations (4) and (5), assumes dynamic similarity of model to trawl, i.e., all forces must have the same model scale.

3. It may not be practicable to produce the mesh size in the model to the size dictated by the application of the basic scale factor. However, a larger mesh size may be used in the model if the resultant difference in resistance is compensated for by the use of a different twine diameter, selected so that the overall hydrodynamic drag forces acting on any section of the full-scale trawl and the corresponding section of the model are related by the correct force scale. This adjustment may be achieved by equating the drag force scale to the gravity force scale utilizing the basic equation for drag:

$$D = C_D \; 1/2 \, \rho \, V^2 A_p \qquad (6)$$

where D is the drag force, is the fluid density, V is the velocity of flow, and A_p is the projected solid area of the netting panel compared. Thus, the ratio A_p between trawl and model can be maintained at the desired level while varying the combination of twine diameter and mesh size to suit available modeling materials. This principle is discussed in some detail in ref. (1).

2.2 Model Tests on the URI Combination Trawl

A total of four trawl models were built and tested. Each of these models was based upon some fundamental concept aimed at producing successive improvements in the design of the URI combination trawl. Hence, the model net trials may be considered in terms of the three phases of increments in improvement to design that were attempted. The three phases are documented in the following sections.

In accordance with the treatment of modeling laws offered by Christensen, ref. (1), the characteristic parameters of the full-scale trawl were reduced to representative model size in the following manner:

Given a full-scale trawl net constructed of five-inch stretched mesh nylon of 54 thread, 0.133" diameter, it is necessary to produce a model constructed of nine-thread, 0.255" diameter nylon. What size mesh should be used in the model?

The basic scaling equation presented in ref. (1) is as follows:

$$\frac{\rho f}{\rho m}\left[C_{1m}\left(\frac{d_m}{b_m}\right) + C_{2m}\left(\frac{d_m}{b_m}\right)^2\right] = \left[C_{1f}\left(\frac{d_f}{b_f}\right) + C_{2f}\left(\frac{d_f}{b_f}\right)^2\right] \qquad (7)$$

where b and d represent the bar length and twine diameter of a mesh respectively, and subscripts "m" and "f" refer to model and full-scale mesh respectively. C is the particular drag coefficient, ref. (4), and subjects "1" and "2" refer to the cylindrical shape of a bar and the spherical shape of a knot of twine between meshes, respectively. ρf is the mass density of full-scale water, i.e., seawater, and ρm is the mass density of the model water, i.e., fresh water.

Standard drag coefficients are readily available, ref. (4), but it is first necessary to compute the Reynolds' Number for the towing conditions of both the full-scale and model trawl. A speed of three knots is assumed for the full-scale trawl and a flow of 1.5 ft./sec. is taken a fairly representative water speed for the model working in the flume tank.

Reynolds' Number is defined as:

$$Re = \frac{v\,b}{\gamma} \qquad (8)$$

where v is the trawling speed at sea or the water flow in the tank, b is the length of a bar of mesh, and γ is the kinematic viscosity of water. From equation (8) the following Reynolds' Numbers may be computed:

$Re_{f1} = 5613$, $Re_{f2} = 16839$, $Re_{m1} = 670$ and $Re_{m2} = 2010$

where subscripts "f" and "m" refer to full-scale and model, and "1" and "2" refer to a cylinder and a sphere representing a bar and knot respectively.

The corresponding standard drag coefficients yielded from the literature, ref. (4), for the conditions of Reynolds' Number stated above are as follows:

$C_f1 = 1.1$; $C_f2 = 0.45$; $C_m1 = 1.1$; $C_m2 = 0.45$.

Now, C_1 and C_2 may be combined in order to simplify equation (1) as follows:

$$C = \frac{C1}{C_2} = \left[\frac{C_{D.Cyl}}{C_{D.Sphere}} \times C_{Shape}\right] \qquad (9)$$

It is readily seen from the coefficient of drag above, when associated with its corresponding Reynolds' Numbers, that C will remain a fairly constant value for a considerable range of conditions. Hence, equation (7) may be further simplified by removing the "f" and "m" subscripts to leave the following expression:

$$\frac{\rho f}{\rho m}\left[\frac{d_m}{b_m}\left(C + \frac{d_m}{b_m}\right)\right] = \frac{d_f}{b_f}\left[C + \frac{d_f}{b_f}\right] \qquad (10)$$

The C resulting from equation (9) and tables, ref. (4), yield the following range of values:

$C = (2.44 \text{ to } 3.11)$

Given $\rho_f = 1.988$ slugs/ft.^{3} and $\rho m = 1.938$ slugs/ft.^{3}, then all values of (10) are known, except for b_m, the size of a bar of mesh for the model trawl. Therefore, equation (10) will be solved to yield b_m for the upper and lower values of C.

Solving equation (10) for b_m when $C = 2.44$

$$\left(\frac{1.988}{1.938}\right)\left(\frac{0.055}{b_m}\right)\left(2.44 + \frac{0.055}{b_m}\right) = \left(\frac{0.133}{2.5}\right)\left(2.44 + \frac{0.133}{2.5}\right)$$

$$\frac{2.44}{b_m} + \frac{0.055}{b_m^2} = 2.313$$

$$b_m^2 - 1.0548b_m - 0.0238 = 0$$

$$b_m = \left[1.0548 \pm \sqrt{1.0548^2 + 0.0951}\right] / 2$$

$$b_m = 1.07''$$

Solving equation (10) for b_m when $C = 3.11$

$$b_m = 1.06''$$

It is clear from these results that little variation in calculated mesh size results over the computed range of C values likely to exist for a given trawl modeling problem. In the practical problem adopted there is only a resultant variation of one hundredth of an inch in bar length for the conditions assumed. Such an amount has no practical significance in the construction of such a model.

The four net models tested were constructed on the basis of this sample.

2.3 Phase 1 of the Model Tests

The URI Series Combination Trawl was designed and built primarily from experience with bottom trawls of the Yankee Series. Measurements made during full-scale trawls, ref. (6) and (7), revealed the severe limitations of the Yankee Trawl (traditionally used in the New England Fishery when applied to the capture of fish swimming clear of the bottom). The headline height of the trawl mouth was conventionally on the order of a fathom, and so the combination trawl was designed to at least double the vertical capability of the trawl while maintaining good bottom-tending capability, ref. (3).

In the design of the URI Series Combination Trawl, every effort was made to retain traditional twine, mesh, and net-section sizes in order that there be some degree of familiarity maintained for the user. It is intended that as this type of fishing gear becomes more acceptable to fishermen, beneficial hydrodynamic modifications may gradually be incorporated into the design for increased fishing efficiency.

More than 100 sets of plans have been forwarded to commercial fishermen throughout the United States, and it is believed that well over a dozen of the nets are in everyday use. A recent survey conducted by the New England Marine Resources Information Program indicated that an average increase in catch of about 25% had occurred for vessels using the URI Series Combination Trawl.

Some users complained of excessive chafing in the region of the lower wings of the net, and it was to explore a means of rectifying this problem that phase 1 of the model tests were conducted.

The first model was built to the standard specifications for the URI Series 280 Combination Trawl, diagram1. The model was streamed in the flume tank with the wing lines aligned and secured as dictated by the scaled-down measurements obtained from full-scale instrumented trials. Observations and measurements were taken from the side, from above, and from within the tank. The velocity of water flow and the changes in resultant performance variables (such as headline height, wingspread, and bottom-tending ability) were viewed in light of the scaled speed, equation (5).

During the tank-testing process, it became apparent that certain minor deficiencies in general design existed in the 280 model. It was observed that throughout a fairly representative range of attitudes, a considerable amount of slack in the twine developed in the bottom part of the lower wings. This observation was important in that it corresponded to remarks

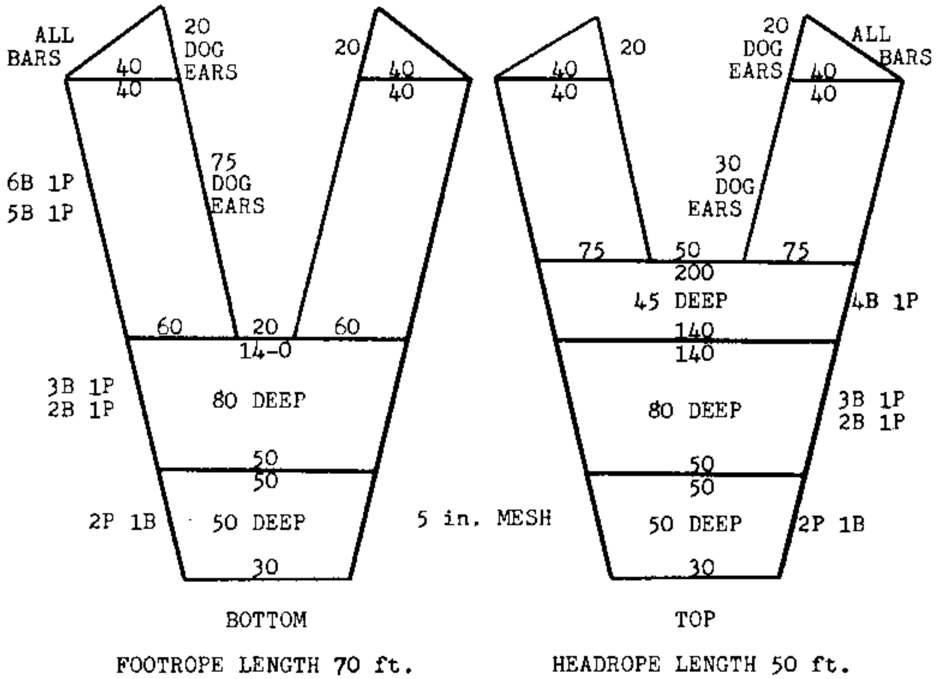


DIAGRAM 1. U.R.I. # 280 COMBINATION TRAWL

made by commercial fishermen using the full-scale trawl. The lower wings extended almost to the horizontal toward the lower belly end, the result of an uneven distribution of stress in the twine. It was this effect that caused the resultant chafing to take place.

A modified 280 model was built and tested in the tank. The design modifications are incorporated in revised net diagram 2, in an attempt to effect a more homogeneous distribution of tension and a better fishing attitude for the trawl.

The primary design changes included (a) removing five meshes from each side of the wide end of the square, thereby reducing the dimensions from 200 to 190 meshes at the wide end; and (b) removing four meshes from the width of both top and bottom wings throughout.

The modified 280 net model was superior in configuration when subjected to water flow. Moreover, a far more homogeneous distribution of stress resulted from the design changes. The lower wings of the net aligned well out of the horizontal throughout their length, with no slack twine apparent. This alleviated the frictional chafing previously experienced in this part of the net.

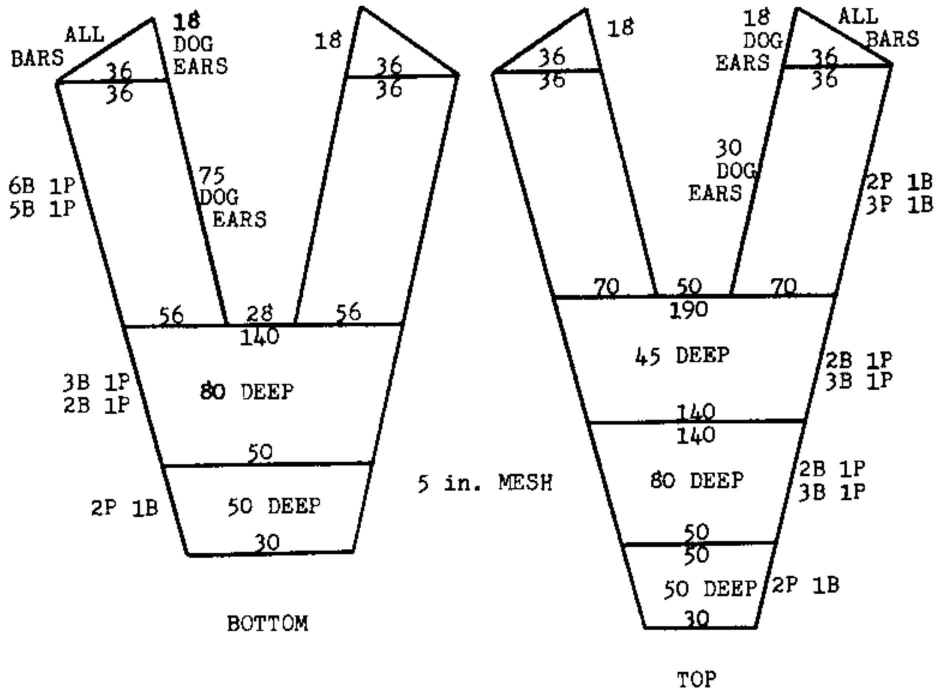
An analysis of measurements collected during the tank trials indicates that no truly significant improvement in dependent performance variables can be claimed for the modified 280 model over the original, Table 1. However, a satisfactory improvement in general net configuration was achieved, benefiting fishing attitude of the trawl.

2.4 Phase 2 of the Model Tests

Although satisfactory performance was achieved with the modified 280 trawl both as a scale model and in commercial use, it was decided to attempt to further increase its ability to catch certain species that swim well clear of the bottom, notably squid. In order to achieve the necessary vertical scope for the trawl, the top and bottom wings were made deeper leaving just ten meshes in the bosom of the net in both the square and the lower belly. The length of the wings was also increased in order that the original headline and footrope lengths of 50 feet and 70 feet be maintained, diagram 3. (Ref. (3) explaines the "hanging" and "tapering" of net sections in detail.) For comparison purposes, a scale factor of 12 was selected for "Phase 1" of the tests, and a scale model built in accordance with the calculations discussed in section 2.2: i.e., 2-inch mesh with 9-thread nylon twine. The model was streamed in the tank under conditions similar to those of the previous experiment, and observations taken as indicated in table 2.

The experiment was designed in order to yield data of a balanced nature for meaningful analysis. As may be readily detected from the table above and the following graphs (Diagram 4), three significant but predictable relationships were confirmed:

(1) The vertical scope of the trawl mouth as represented by the dependent variables of headline height and wing-end height is significantly increased by adding buoyancy floats.



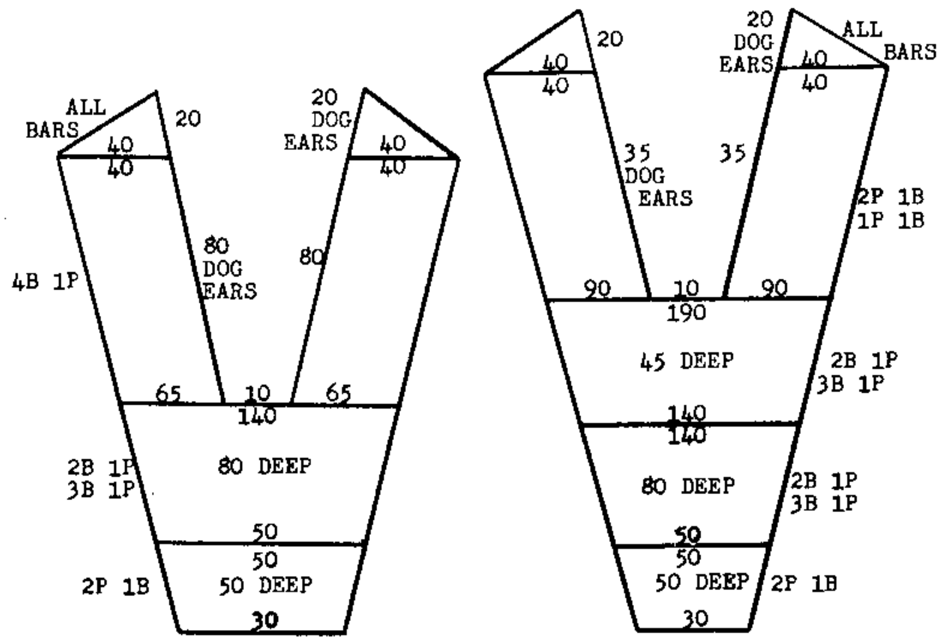
FOOTROPE LENGTH 70 ft. HEADROPE LENGTH 50 ft.

DIAGRAM 2. U.R.I. MODIFIED # 280 COMBINATION TRAWL

- 6% greater hanging line than sweep
- Bosom hung 1.5 : 1

	GEAR ARRANGEMENT 35 CANS SCALE 1 : 12	WING SPREAD	HDLN HT	WING HT	OFF BOTTOM
280 MODEL	EVEN LEGS	24	8	7	1
	TOP LEG SLACK 5"	21	11	9	2
	INSERT THIRD BRIDLE	24½	12½	10	0
	SLACK MIDDLE BRIDLE 2"	24	11	9	0
	INCREASE BRIDLES 10"	24½	13	11	0
	INCREASE AND ADD 3 FLOATS	24	15½	13	0
	ADD 3 FLOATS BUT NO INCREASE	24	14	12	0
280A MODEL	EVEN LEGS	23	9	7	0
	TOP LEG SLACK 5"	21	10½	9	2
	TOP LEG SLACK 3"	22	9½	8	0
	SLACK 3" AND ADD 3 FLOATS	21	11½	9	0
	INSERT THIRD BRIDLE	22	12	9	0
	THIRD BRIDLE AND ADD 3 FLOATS	21	14	10	0

Table 1. Phase 1 Tank Test Data



BOTTOM

TOP

FOOTROPE LENGTH 70 ft.

HEADROPE LENGTH 50 ft.

DIAGRAM 3. DEEP WING 280 COMBINATION TRAWL

Number of Floats	Arrangement of Legs	Equivalent Towing Sp'd in Kts	Headline Height	Height at Wing Ends
17	even	2.8	11½	10
		3.5	9	7½
	Top + 6	2.8	12½	10½
		3.5	10½	8½
30	even	2.8	13	11½
		3.5	11	9
	Top + 6	2.8	14	12
		3.5	11½	10
40	even	2.8	---	---
		3.5	12½	11
	Top + 6	2.8	---	---
		3.5	13½	10½

Table 2. Phase 2. Tank Test Data

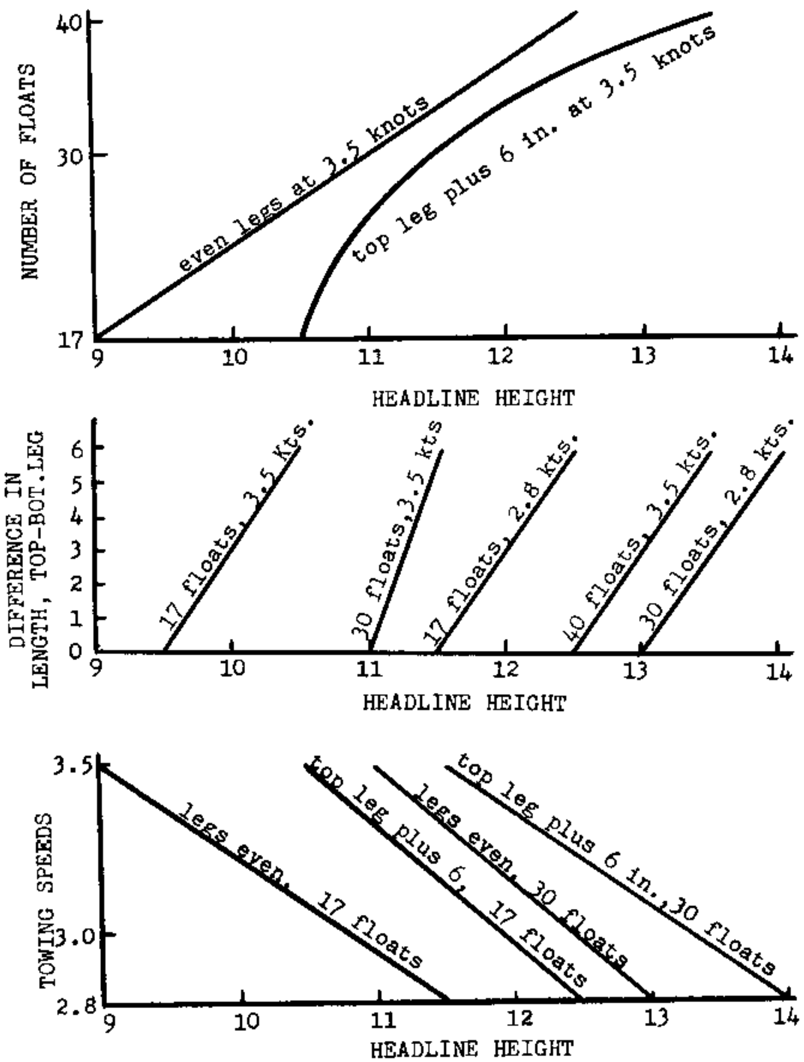


DIAGRAM 4. GRAPHS OF TANK TEST DATA, PHASE 2.

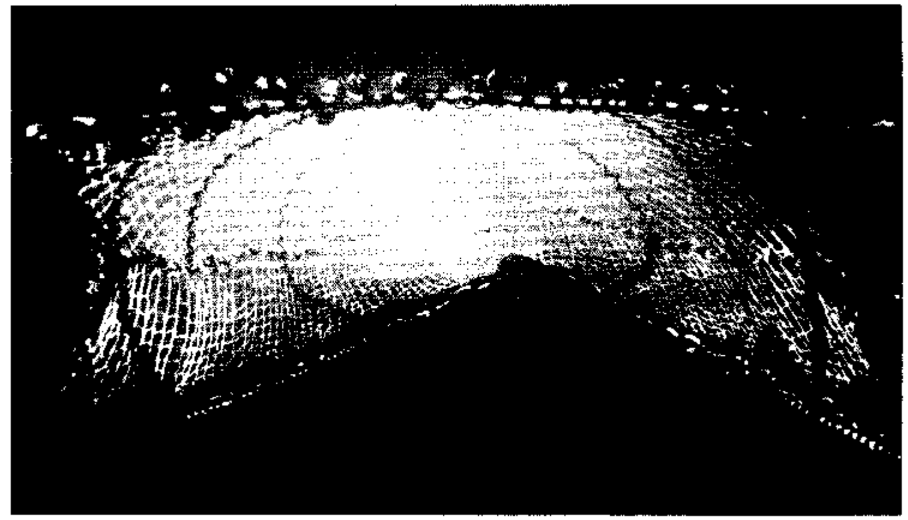


Plate 2. Phase 2 Trawl Model in the Flume

(2) The interrelationship between wingspread and headline height and wingspread of the trawl was confirmed. Note: The wing lines were directed in the tank as dictated by observations from full-scale instrumented trials, ref. (6).

(3) For the levels adopted, a significant increase in headline height resulted from slacking back the top leg, ref. (6) and (7).

Due to certain minor differences in method of construction and materials available for appendages to the nets, no attempt was made at direct performance comparison between the model net used in Phases 1 and 2 of the experiments. Moreover, although the model net used in the Phase 2 experiment performed in a predictable fashion as far as the variance of certain design factors was concerned, there were some apparent deficiencies and irregularities in general design features caused by the deep-wing arrangement and the subsequently reduced "bosom" section, ref. (3).

In general terms, the footrope configuration assumed more of a "V" shape than the characteristically smooth catenary usually regarded as optimal, Plate 2.

The arrangement of the lower part of the net resulted in diminished bottom-tending ability, one of the desirable features of a good combination trawl. A further drawback of the deep-wing design was the fact that the net appeared badly formed, with an irregular distribution of stress throughout the square and inner part of the top wings in the region of the headrope.

Because of the apparent design deficiencies revealed by tank testing, the deep-wing modifications of the 280 trawl were rejected at the experimental stage, and further improvements in design were concentrated in an alternate direction during "Phase 3" experiments as follows.

2.5 Phase 3 of the Model Tests

For the third and final phase of this series of model tests, a model trawl was built to the general design specifications of the Modified URI 280 Combination Trawl, Diagram 2, with the following changes:

(1) The hanging ratio of the 50 and 28 meshes constituting the 'bosom' part of the top and bottom of the trawl, Diagram 2, was revised from 2:1 to 1.5:1. Fifty 5-inch meshes of the lower belly and twenty-eight 5-inch meshes of the upper belly were hung in (5/1.5 = 3 1/3) inches of hanging line and headrope respectively rather than (5/2 = 2½) inches utilized in the trawl design used for Phases 1 and 2. Thus, the bosom part of the headrope and footrope was increased from 5.8 feet to 7.8 feet and 10.4 feet to 13.9 feet respectively.

NOTE: Where the hanging ration or coefficient is expressed as a percentage,

$$\text{Hanging Ratio} = \frac{\text{(Stretched Mesh-Hanging Length for 1 Mesh)}}{\text{Stretched Mesh}} \times 100 \text{ percent.}$$

This results in a hanging ratio of 33-1/3 percent in the bosom section, rather than the previously used 50 percent.

(2) Because the bosom sections of headrope and footrope were increased 2 feet and 3.5 feet respectively, it was necessary to reduce the length of the top and bottom wings by two meshes and four meshes respectively. This was done to use the same headrope and footrope lengths of 50 and 70 feet and to maintain a tight 1:1 or 100% hanging ratio throughout the wing sections of the net, ref. (3).

The model net incorporating the alterations referred to in (a) and (b) was subjected to test conditions similar to those of the Phase 2 model, and although little variance from the data listed in table 2 and the trends illustrated in Diagram 4 resulted, a considerable improvement in general design was apparent. The resultant stress distribution was homogeneous throughout the net, with an ideal footrope configuration and none of the design irregularities apparent in the Phase 2 experiment.

A photograph of the Phase 3 model streamed in the flume tank is shown in Plate 3.

The revised trawl appeared to tend the tank bottom more effectively (an important consideration for a combination trawl) and adopted a generally more balanced appearance when subjected to water flow than the other trawl model.

Plate 3. Phase 3 Trawl Model in the Flume

III. CONCLUSIONS

It is an extremely difficult but not impossible task to produce a scaled-down replica of a full trawl system. It is virtually impossible to duplicate a fishing environment in test tank form, and it is mainly this difficulty of environmental simulation that renders the direct transfer of behavioral information of a quantitative nature from model to full-scale trawl an uncertain method of evaluation. Furthermore, various dynamic oscillations of gear components in motion--possibly due to some irregular frictional or hydrodynamic effect on a particular section of the full-scale working trawl--are not revealed by tank testing a scale model.

Certain gear specialists believe that such periodic, unsteady motions of gear components--such as ground cable and warp vibration, headline oscillation, and fluctuations in otterboard aspect--may be extremely important contributors to a trawl's fish-catching ability. The physical dimensions of test tanks do not usually facilitate the operation of a scale model of sufficient size to realistically represent the dynamic, behavioral characteristics and attitudes of the various component parts of the trawl.

The true value of tank testing scale-model trawls appears to lie in the contribution that experiments can make toward the optimization of design and hydrodynamical flow features. The design and flow considerations should be directed toward minimizing resistance and optimizing the attitude of the trawl for the species for which the trawl is to fish.

In general, the models tested reacted to component variation much in the way expected from experience with similar changes made in full-scale trawls. For the limited scope of the test trials of models conducted to this date, the advantage of such a method of determining the behavior of gear seems confined to facilitating observations of qualitative design features in the trawl net itself. It can not provide an overall view of the total trawl system and its working environment. In a more practical sense, observation of scale models may provide sufficient insight into the physical interaction of various component and performance factors to highlight areas worthy of close attention in full-scale instrumented trials. Thus, the more expensive, instrumented-trials method of determining trawl performance may be rendered more efficient and economical. Notwithstanding the foregoing, a considerable amount of knowledge has been gained by these writers regarding the performance of trawl systems by means of the medium of scale modeling.

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